OBSERVATIONS ON COLONIZATION OF SUBSIDED SHORELINES AT HALAPE AND KEAUHOU, HAWAI'I

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ABSTRACT

Several miles of shoreline below Kīlauea volcano (Hawai'i) experienced sudden slip-fault subsidence of about 4.5 m. Newly-formed shallows examined 4.5 months after submergence harbored low-diversity invertebrate populations that were largely herbivorous. Increased springwater flow provided an influx of nutrients to protected shallows and apparently enhanced growth of algal mats. No new coral colonies were seen and most available substrate contained calcareous algae (in high water motion areas) or diatom/detritus mat (in calm water areas). Macroalgae were rare and where present were intensely grazed. Fishes commonly associated with corals were conspicuously absent and two species of snappers (lutjanids) were very abundant around submerged debris. Near freshwater sources, thriving brackish water fauna were present. Some similarities in the early colonization of the shoreline locales and of succession in flow-through laboratory microcosms are noted.

OBSERVATIONS AND COMMENTS

During an earthquake on 29 November 1975, a section of the southeast coast of Hawai'i from about Kalue to 'Āpua Point subsided about 4.5 m. Old shoreline was permanently inundated by the event and destruction of intertidal communities was widespread. Prior to subsidence, Ball (1976) surveyed some shallow tide pools in the Halapē area in July 1975 and provided a proximate inventory of marine flora and fauna. Also given in that report are general descriptions of the history and setting of the area and summaries of previous marine surveys along that coast. The following observations at Halapē and Keauhou were made during a trip on 15-16 April 1976 (3.5 months after subsidence).

At Halapē (Fig. 1), the old shoreline grove of about 75 coconut trees was below sea level in what is now surf zone. Most of the trees were still standing although a few downed trees had been washed onto the newly-formed beach. This beach was white

sand and relatively steep with a 1.2- to 1.5-meter berm located 9 to 12 m backshore. Immediately inshore of the inundated grove, a 60 meter-long crescent-shaped beach about 25 m wide had formed. To the east of the grove along the more exposed shoreline, there was a 12 meter-wide beach about 120 m long. The old shoreline was an estimated 90 to 180 m seaward of the present shoreline and was covered with about 1.5 m of water.

Shells of intertidal molluscs probably killed by abnormally deep submergence were common on the newly-formed beaches. Adult and subadult 'opihi (Cellana spp.) and humpback cowries (Cypraea mauritiana) were most abundant. Also abundant along the protected crescent beach were adult and subadult bubble shells (Bulla adamsi).[1] This latter occurrence is remarkable since these shells are fragile and therefore do not persist as recognizable beach litter. Their abundance suggests that an unusually large population of this mollusc was currently resident in the area. Littorines (periwinkles) were common on protected rocks, but no live 'opihi or cowries were observed during a survey of 500 m of rocky shoreline from Halapē to Turtle Bay (west of Halapē at the base of Pu'u Kapukapu). During previous visits in the 1960's both molluscs were common along this same stretch of coastline. Grapsid crabs ('a'ama) were also seen during this survey, but the population was obviously smaller than normal. One sea turtle (unidentified species), about 0.6 m long, was seen just offshore of the crescent beach. Surf at the time of the observations was 0.6 to 1.5 m and inshore waters were very turbid.

A large crescent-shaped fault crack situated about 150 m inland at Halapē was previously 4 to 6 m across but had widened to about 9 m and subsided several meters. The brackish water pools which existed previously have enlarged and deepened; their water now tastes potable, being only slightly salty. The shrimp (palaemonid spp.) and 'o'opu (gobiid fish) which were previously common in these pools were absent. No living macrofauna were observed. The walls and bottoms of these pools were covered with what appeared to be early successional algal growth, a thick brown cotton-like mat. These changes are undoubtedly the result of the tsunamis which overran the crack, flooding it and washing out the established brackish-water community.[2]

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[1] Bulla adamsi has also occurred in large numbers during the early recovery stages of copper-killed microcosms at Naval Ocean Systems Center, Mōkapu, O'ahu, as has the sea hare Stylocheilus longicauda. Both species appear to thrive when predatory crustaceans are few or absent.

[2] Established populations of prawns (Macrobrachium sp.) and two species of shrimp (palaemonids ?) were evident in the pools during a revisit of the area by R. S. Henderson in August 1977.

The shoreline between Halapē and Keauhou (approx. 3 km east) used to be low rock cliff, rising 2.5 to 6 m above the surf. Subsidence has brought these cliffs to or below sea level. The small offshore island of Keaoi has been reduced in area by about 75%. The debris lines left by the tsunamis were conspicuous and, where the relief is low, were situated as far as 270 to 360 m inland of the present shoreline. Common dead organisms in this debris were spiny lobster (Panulirus pencillatus), triggerfish (balistids), and starfish (ophidiasterids). At Halapē, the greatest elevation of this debris line was about 9 m above sea level. Between Halapē and Keauhou, it was about 6 m above sea level.

At Keauhou, the shoreline had been altered drastically, (Fig. 2). A peninsula with a westward-facing low cliff about 1 to 2 m above sea level previously extended seaward for several hundred meters forming a small embayment which was moderately protected from the predominating easterly swell. A small grove of kiawe trees (Prosopis pallida (Humb. & Bonpl. ex Willd.) HBK.) had stood on this peninsula; however, after the tsunami the only remaining kiawe trees were those on higher terrain near the water cistern shown in Figure 2. The subsidence had greatly increased the complexity of the shoreline. A narrow peninsula barren of kiawe trees now projected west, creating an irregular embayment to the northwest and a second triangular embayment to the southeast. The northwest embayment provided a large area of shallow protected water. Low mounds of pāhoehoe were exposed at low tide both across the mouth of the twin embayment and immediately offshore of the westward projecting peninsula. Along the landward margins of the twin bays, abundant spring flow was observed during a 0.08-meter tide. Estimated flows were 4000 lpm or greater. A water sample taken from a brackish pool formed in a land-locked depression at high tide (+0.6 m) measured 3.6‰ salinity. Subsidence at Keauhou was about 4.5 m, as was clearly indicated by an old benchmark labeled +15 feet (4.5 m), which is now located within 0.3 m elevation. Most of the land area was strewn with branches and broken trunks of kiawe trees. Even large kiawe trunks over 0.3 m in diameter were broken into 1- to 2-meter segments.

On 16 April 1976, snorkeling observations were made in the twin embayments. In the shallows furthest inshore, a 0.3-meter layer of brackish water is evident at the surface. A thick brown-colored layer of algal mat[3] closely resembling that seen in the crack at Halapē covers nearly all substrate in this area. A similar brown mat was observed in Kapoho Bay, (Puna coast, Hawai'i) in 1960 after the temperature in the bay had been raised

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[3] Microscopic examination of algal material of similar appearance found in a low-flow microcosm at Naval Ocean Systems Center, Mōkapu, O'ahu, revealed the following composition: 50% detritus, 30% diatoms (Gyrosigma, Navicula, Nitzchia, & Thallosira), 10% dinoflagellates (Amphidinium & Gonyaulax), and 10% copepods.

to about 40°C for several days due to nearby influx of molten lava. In the intertidal zone at Keauhou, some small patches of green algae (Enteromorpha sp.) were observed. In the shallow inshore areas, manini (Acanthurus sandvicensis), 'o'opu (Bathygobius fuscus), pāo'o (Istiblennius zebra), āholehole (Kuhlia sandvicensis), and 'ama'ama (Mugil cephalus) were common. Also seen were maomao (Abudefduf abdominalis), maiko (Acanthurus nigroris), pualu (Acanthurus xanthopterus), kīkākapu (Chaetodon lunula), lolo (Coris gaimardi), kūmū (Parupeneus porphyreus), and kākū (Sphyraena barracuda). Further seaward but inside the surf zone, wrasses (labrids), butterfly fish (chaetodontids), and surgeon fish (acanthurids) were common (Table 1). The snappers (lutjanids) Lutjanus kasmira and L. fulvus were also very common, especially among clumps of fallen and submerged kiawe trees.[4] Parrot fish (scarids) were conspicuously absent, probably because of the lack of corals and diverse algal growth. No newly settled coral colonies were observed.[5] Benthic macroalgae were generally uncommon here. When present, they were usually stubby or coarse-filamentous in appearance. In the shallower portion of these new embayments, the turbid waters, abundant debris, and resident fish population created an underwater aspect more closely resembling mangrove shallows than an exposed rocky coast.

Observations on invertebrates during this snorkel survey were necessarily casual. Noteworthy in the Keauhou area was the abundance of the barnacle Tetraclita pacifica, usually not overly common in exposed rocky environments. Two species of vermetid worms (probably Vermetus alii and Dendropoma platypus) were common. Also seen in the Keauhou embayments were: sea urchins (Echinothrix diadema and Diadema paucispinum), both common; periwinkles, very common; bubble shells, uncommon (unlike at the beach at Halapē); 'a'ama, uncommon; and one 'opihi about 2 cm in maximum basal dimension.

The newly formed shallow embayments at Keauhou serve as a fair replacement for the protected waters that used to exist between Halapē and Keaoi Island. The large area of brackish-water influenced shallows is well on its way to becoming a productive nursery abounding with juvenile fish species. The bottom immediately inside the surf zone will, in time, develop a typical open-coast coral community. The Keauhou embayments are well

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[4] The abundance of lutjanids among the debris is particularly interesting when one recalls that R. Grigg (in 1971 EPA report) reported a similar abundance in and around the debris plumes from sugar mills along the Hāmākua Coast. Grigg also reported finding bagasse in a few lutjanid stomachs.

[5] In a revisit of the area by R. S. Henderson in August 1977, many small colonies (1-3 cm diameter) of the corals Pocillopora meandrina and Porites lobata were noted in shallows not affected by fresh water. With the increasing water motion of the surf zone, calcareous algae were the dominant algal forms.

suited to safe snorkeling, a rare situation for this section of the Puna coast. In addition, the Keauhou embayments present an excellent opportunity for the quantitative study of successional recovery of both a protected brackish-water and a surf-zone environment.

LITERATURE CITED

Ball, F. W. 1976. Halapē marine survey. CPSU/UH Tech. Rep. 10 (Dept. of Botany, University of Hawaii). 51 pp.

Environmental Protection Agency. 1971. The Hawaiian sugar industry waste study. Submitted to EPA, Region 9, San Francisco, CA.

TABLE 1. Fish species observed inshore at Keauhou, Puna Coast, Hawai'i, 16 April 1976.

FAMILY Scientific Name	Common/Hawaiian Name
ACANTHURIDAE - Tangs	
Acanthurus guttatus	Tang
A. nigroris	Maiko
A. sandvicensis	Manini
A. xanthopterus	Pualu
Ctenochaetus strigosus	Kole
Naso lituratus	Tang
Zebrasoma flavescens	La'ipala
BLENNIIDAE - Blennies	
Istiblennius zebra	Pao'o
CHAETODONTIDAE - Butterfly Fish	
Chaetodon auriga	Kīkākapu
C. lunula	Kīkākapu
C. miliaris	Kīkākapu
C. quadrimaculatus	Kikakapu
GOBIIDAE - Gobies	
Bathygobius fuscus	'O'opu
KUHLIIDAE - Sea-mountain Bass	
Kuhlia sandvicensis	Āholehole
LABRIDAE - Wrasses	
Anampses cuvieri	Hilu
Coris gaimardi	Lolo
Thalassoma ballieui	Hinalea luahine
T. umbrostigma	Hinalea

TABLE 1--Continued.

FAMILY Scientific Name	Common/Hawaiian Name
LUTJANIDAE - Snappers	
Lutjanus fulvus	Toau
L. kasmira	Taape
MUGILIDAE - Mullets	
Mugil cephalus	'Ama'ama
MULLIDAE - Goat Fish	
Mulloidichthys samoensis	Weke
Parupeneus porphyreus	Kūmū
POMACENTRIDAE - Damsel Fish	
Abudefduf abdominalis	Maomao
SPHYRAENIDAE - Barracuda	
Sphyraena barracuda	Kākū

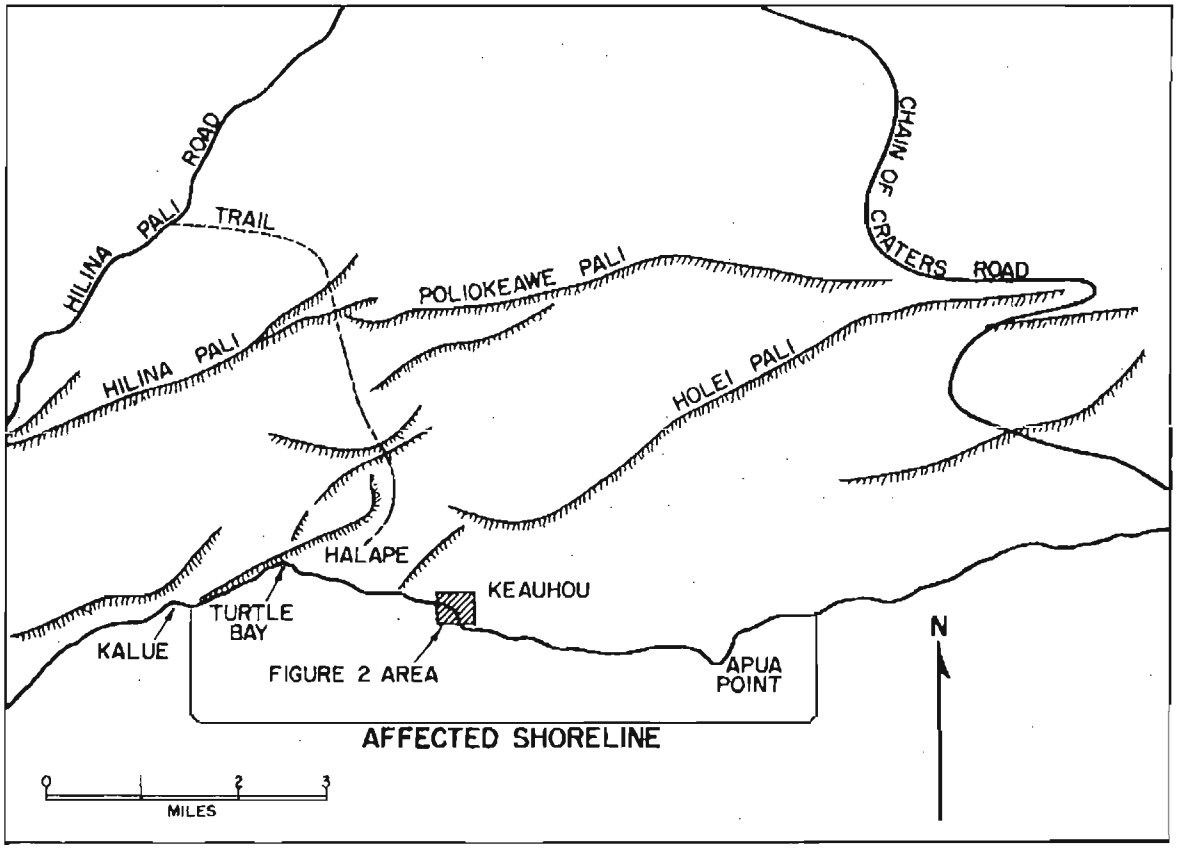

FIGURE 1. Map showing area of Puna coast, Hawai'i, that was most heavily impacted by shoreline subsidence.

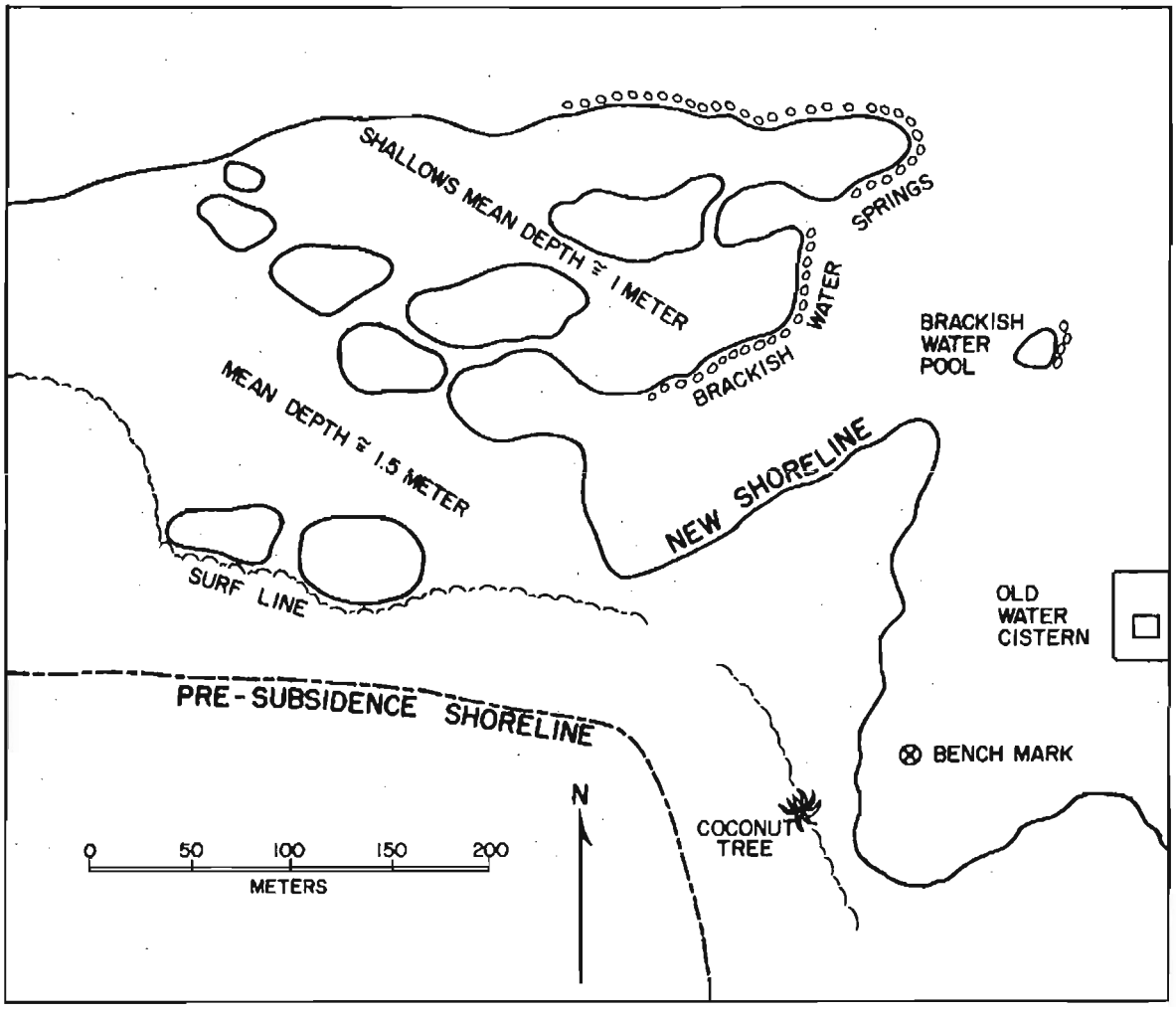

FIGURE 2. Estimated post-subsidence shoreline configuration of Keauhou bay, Puna coast, Hawai'i.